DNA 2524H
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THE TRAPPED RADIATION HANDBOOK

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Revised
1 November 1973

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Prepared for:
Defense Nuclear Agency
Washington, D.C. 20305
by Lockheed Palo Alto Research Laboratory
Under Contract DNA 001-73-C-0065
NWER Subtask HC047-08

Published by:
DASIAC
General Electric Company—TEMPO
Santa Barbara, California 93102
Under Contract DNA 001-74-C-0014
NWED Subtask DC001-08

Approved for public release; distribution unlimited

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Table 6-1. High-altitude nuclear detonations.

Event	Altitude (km)	Time (U.T.)	Date	Latitude	Longitude	Approximate L-Value of Detonation	Yield	Characteristics of Band	Approximate Decay Time
Teak	76.8	10:50:05	1 Aug 1958	17°N	169°W	1.12	MT Range	Low Altitude	~few days
Orange	42.97	10:30:08	12 Aug 1958	17°N	169°W	1.12	MT Range	Low Altitude	~1 day
Argus 1	~200	2:30:00	27 Aug 1958	38°S	12°W	1.7	1-2 KT	Narrow Band	0-20 days
Argus 2	~250	3:20:00	30 Aug 1958	50°S	8°W	2.1	1-2 KT	Narrow Band	10-20 days
Argus 3	~500	22:10:00	6 Sept 1958	50°S	10°W	2.0	1-2 KT	Narrow Band	10-20 days
Starfish	400	09:00:029	9 July 1962	16.7°N	190.5°E	1.12	1.4 MT	Wide Distribution	1-2 years
USSR 1	—	03:40:46	22 Oct 1962	—	—	~1.8	—	Wide Distribution	~30 days
USSR 2	—	04:41:18	28 Oct 1962	—	—	~1.8	—	Wide Distribution	~30 days
USSR 3	—	09:13:	1 Nov 1962	—	—	1.75	—	Narrow Band	~30 days

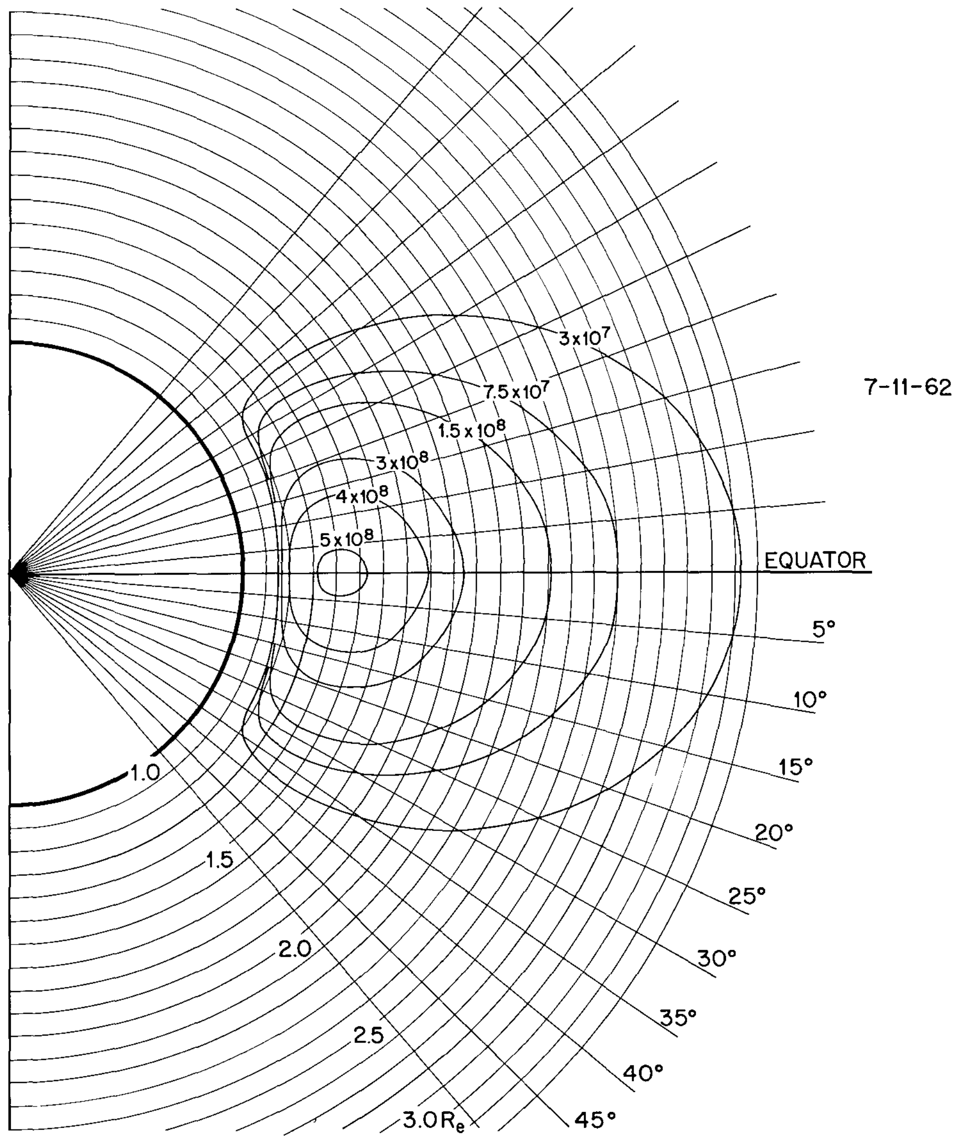

Figure 6-16. Flux contours 2 days after Starfish, as determined from Telstar data by Newkirk and Walt (unpublished).

6.5 USSR DETONATIONS IN 1962

6.5.1 Introduction

In the fall of 1962, the Soviet Union conducted three high-altitude nuclear weapons tests that produced significant trapping of high-energy electrons. The dates and approximate times of these detonations are given in Table 6-1.

Data on the trapped electrons were obtained by a number of satellites including Telstar 1, Explorer 14, Alouette, Starad (1962 βK), and Explorer 15. Characteristics of these satellites are listed in Table 6-8. Since Starad and Explorer 15 were instrumented specifically to observe the fission-spectrum electrons from Starfish (which occurred on 9 July 1962), the information obtained on the USSR detonations with these two satellites is especially valuable. Unfortunately, both satellites were launched after the 22 October explosion and, therefore, give little information for that event.

Section 6.5.2 summarizes the available trapped electron information that resulted from these explosions. In Section 6.5.3, an assessment of the total inventory of trapped electrons is presented.

6.5.2 Summary of Trapped Particle Data

22 OCTOBER EVENT. Trapped electrons from the 22 October explosion were observed by Telstar, Alouette, and Explorer 14 soon after the detonation. The residual radiation was seen some days later by Explorer 15. Since the orbits of these vehicles were appreciably different, observations were made at significantly different altitudes. Alouette, being a circular polar orbit at $\sim$1,000 kilometers, intercepted the band at low altitude, whereas the Explorer 14 crossings were near the equatorial plane. Telstar, having moderate inclination, is perhaps the most favorably situated of the three. All three satellites had instruments designed to measure natural radiation. Consequently, the energy sensitivities were not optimum for fission-spectrum electrons.

According to measurements made by Alouette, a broad band of electrons was injected, extending from a sharp inner boundary at about $L = 1.8$ to $L = 6$. Explorer 14, on the other hand, did not observe an increase beyond about $L = 3.6$ to 4.2. However, because of the higher natural background experienced by Explorer 14 (due to lower detector thresholds and higher altitude of L-intercepts), Explorer 14 would not have detected a flux of the magnitude seen by Alouette at L > 3.6. Hence, injection probably did occur to about L = 6. A double maximum in the L-profile of the belt was suggested by Alouette's data. This observation was confirmed by passes of Explorer 15 made shortly before the second Russian shot.

The most complete flux distributions for this event were derived from Telstar's counting rates (Reference 56). A plot of omnidirectional fluxes in R, λ coordinates is shown in Figure 6-23. The dotted

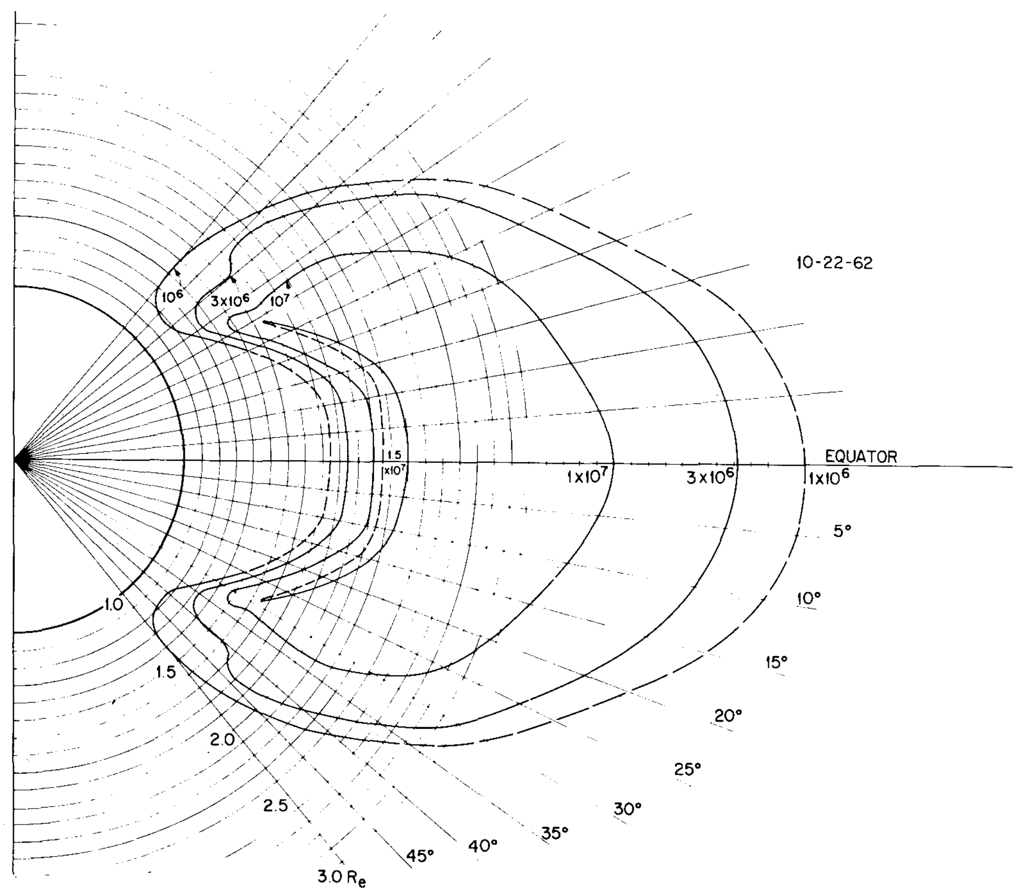

Figure 6-23. Omnidirectional flux (cm^{-2} sec^{-1}) contours (Telstar data) immediately following the Russian test of 22 October 1962 (Reference 56).

contours denote extrapolations based on the spatial derivatives of the flux in the measured regions (solid lines). The numbers shown represent the flux values immediately after injection.

28 OCTOBER EVENT. Because of the large number of radiation measuring satellites in orbit at the time of detonation, the trapped radiation from the 28 October event is better known than that of any other high-altitude nuclear explosion. In particular, the two satellites Explorer 15 and Starad were instrumented to measure energy spectra and angular distributions of fission-fragment electrons. Unfortunately, because the spin rate of Explorer 15 was larger than planned, angular distribution information was not recovered. In the case of Starad, the telemetry and timing system introduced noise and position errors, thereby reducing the value of that satellite. By careful study, some of these difficulties have been overcome, yielding a fairly complete analysis of some of the data from the 28 October test (Reference 38).

In many respects, the trapped radiation produced on 28 October resembled that produced on 22 October. The trapped band had a sharp inner boundary at $L \approx 1.8$ and extended to $L \approx 3.0$ as seen by Alouette and Explorer 15. A well-defined double maximum was apparent with peaks at $L \approx 1.82$ and $L \approx 2.17$ (values slightly B-dependent). A detailed analysis (Reference 38) was presented based on information from a directional spectrometer carried on Starad. From the pitch angle distribution (confirmed in Reference 57), it is clear that a major injection occurred at low altitudes. Several different experimenters report that the energy spectrum was not an equilibrium fission spectrum, at least at some positions. This result implies either that the debris motion extended over many minutes or that some electromagnetic effect altered the energy after the electrons were injected.

Omnidirectional fission-electron fluxes from Telstar also were computed for this event and are given in Figure 6-24 for time zero (Reference 56). In the analysis resulting in the figure, the energy spectrum was assumed to be a fission spectrum at all points, an assumption known to be incorrect. However, the Telstar detector (threshold ≈ 0.4 MeV) is not very sensitive to spectrum changes of the type observed. The contours in the region $L \approx 2$ show maximums off the equator in agreement with the conclusions of West that the injection was at low altitude.

1 NOVEMBER EVENT. The distribution of trapped electrons from the 1 November event was qualitatively different from the two previous

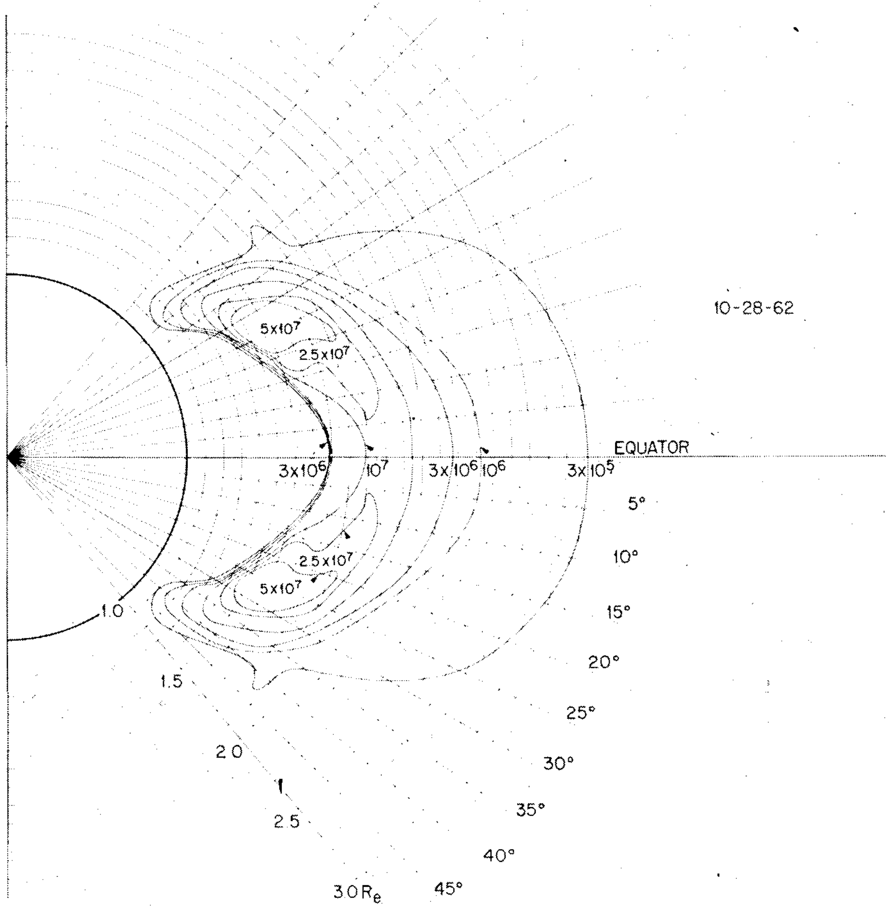

Figure 6-24. Omnidirectional flux (cm^{-2} sec^{-1}) contours (Telstar data) immediately following the Russian test of 28 October 1962 (Reference 56).

ones in that the injection was confined to a narrow band centered at L = 1.766 with a full width at half maximum in the equatorial plane of about 250 kilometers. The best readily available data describing the narrow band and its subsequent decay are given in Reference 23.

No pitch angle distributions have been published, but the observed B-independence of the omnidirectional flux measured by Explorer 15 implies (with some uncertainty) that injection occurred along the entire field line.

6.5.3 Electron Inventories

22 OCTOBER EVENT. Electron inventories for the 22 October event have been obtained from Explorer 14 and Telstar data, and a lower limit to the inventory has been estimated from Alouette data. From Explorer 14 results, Van Allen (Reference 26) estimated that 1.5×10^{24} electrons with energy greater than 230 KeV were trapped (also, see Reference 36). However, this number is questionable because of uncertainties in the geometric factor for fission-spectrum electrons, high natural background, and the restricted spatial coverage. Van Allen was unable to detect any injection above $L = 3.6$, whereas Alouette clearly indicated that high-energy electrons were present out to about $L = 6$.

The Alouette orbit was in the low regions of the radiation belts. However, if the omnidirectional flux is assumed to be constant along field lines, a lower limit to the inventory can be estimated. From the L-shell profile of orbit 316 published in Figure 5 of Reference 35, one derives $>1.15 \times 10^{23}$ electrons above 3.9 MeV or a total electron inventory $>2.9 \times 10^{24}$ electrons, assuming that 4 percent of the fission electrons are above the nominal detector threshold of 3.9 MeV.

The most complete spatial coverage for the 22 October event was given by Telstar (Figure 6-23). The total population derived from that figure is 4.8×10^{25} electrons.

28 OCTOBER EVENT. Similar analyses were made of the Alouette data and the Telstar count rates for the 28 October detonation. The data of Pass 298, shown in Figure 6 of Reference 35, were used for Alouette and gave an inventory of $>3.5 \times 10^{22}$ electrons above 3.9 MeV, or a total of $>8.8 \times 10^{23}$ electrons. The total inventory derived from Telstar data plotted in Figure 6-24 is 1.6×10^{25} electrons. West (Reference 38), using Starad results, obtains inventories of $2.0 \pm 1 \times 10^{25}$, $1.2 \pm 0.5 \times 10^{25}$, and $5.9 \pm 2 \times 10^{24}$ for electrons above 0.2, 0.5, and 1.0 MeV, respectively. From a separate instrument on the same satellite, 5×10^{24} electrons above 1.2 MeV were obtained as cited in Reference 39.

1 NOVEMBER EVENT. Computation of the electron inventory for the 1 November 1962 explosion were derived for three energy thresholds from the published electron fluxes of Brown (Reference 23):

- $E > 0.5$ MeV 5.6×10^{23} electrons
- $E > 1.9$ MeV 2.8×10^{23} electrons
- $E > 2.9$ MeV 8.5×10^{22} electrons .

The ratio of these values is in reasonable agreement with that of a fission source. The value for the 0.5 MeV threshold is rather inaccurate, however, because of the higher background at low energy.

The inventories for the three tests are summarized in Table 6-10, where the first column identifies the satellite, the second column shows the total number of electrons above the detector threshold, and the third column presents the total number of fission electrons detected, assuming that the energy distribution was an equilibrium fission spectrum. The last column includes an adjustment, where available, to correct for factors specified in the footnotes, and gives quantities that are to be compared. There are factors of 10 disagreement in the face values of the inventories for the first two USSR detonations.

The most probable values for the inventories were selected thus: For the 1 November event, the only data available are those of Brown (Reference 23). The internal consistency in his results for the 1 November event and the agreement between the spot checks of his Explorer 15 data with other data for the 28 October electron fluxes argues that the inventory is probably good to better than a factor of 2. Of the three inventory values, the 1.9 MeV threshold result is preferable. The >0.5 MeV channel had high background, and the >2.9 MeV channel contains such a small fraction of the fission spectrum that the inventory is critically dependent on the detector energy sensitivity.

For the 22 October detonation, most of the data has large uncertainties. The orbital period of Explorer 14 was too long for good sampling, and the background was so high that the bomb electrons were not discernible above $L = 3.5$. Alouette was in a low-altitude orbit and did not sample the most intense fluxes. Furthermore, the geometric factor of the >3.9 MeV detector on Alouette is probably very uncertain since the straggling of electrons in 1.4 grams per square centimeter of material is very difficult to estimate. Telstar has the best orbit but the detectors have poor energy selectivity for fission-spectrum electrons. However, in spite of the uncertainties

Table 6-10. Electron inventories for the USSR tests.

Satellite	Measured Value		Total Observed Electrons E > 0	Inventory Estimate
22 October				
Explorer 14	1.5×10^{24}	E > 230 KeV (L < 3.5)	1.8×10^{24}	4.5×10^{24} [a]
Alouette	1.15×10^{23}	E > 3.9 MeV	2.9×10^{24}	2.9×10^{24}
Telstar			4.8×10^{25}	4.8×10^{25}
28 October				
Explorer 14	1.5×10^{24}	E > 230 KeV	1.8×10^{24}	3.6×10^{24} [b]
Alouette	3.5×10^{22}	E > 3.9 MeV	8.8×10^{23}	8.8×10^{23}
Telstar			1.6×10^{25}	1.6×10^{25}
Starad (Reference 39)	5×10^{24}	E > 1.2 MeV (L > 1.9)	1.2×10^{25}	1.35×10^{25} [c]
Starad (Reference 38)	2.0×10^{25}	E > 200 KeV	2.3×10^{25}	2.3×10^{25}
	1.2×10^{25}	E > 500 KeV	1.7×10^{25}	1.7×10^{25}
	5.9×10^{24}	E > 1.0 MeV	1.2×10^{25}	1.2×10^{25}
1 November				
Explorer 15	5.6×10^{23}	E > 0.5 MeV	7.9×10^{23}	
	$2.8\ 10^{23}$	E > 1.9 MeV	1.19×10^{24}	1.2×10^{24}
	8.5×10^{22}	E > 2.9 MeV	8.0×10^{23}	

Notes:

[a] Increased by 25 percent for electrons at L > 3.5 on the basis of the Telstar distributions and increased by a factor of 2 to allow for a rapid decay in the 2 days between injection and sampling by Explorer 14.

[b] Increased by a factor of 2 to allow for the decay between the 28 October and the sampling period on ~ 30 October.

[c] Increased by 12 percent for electrons at L < 1.9 on the basis of the distributions measured with Telstar.

in the geometric factor of Telstar, the ratio of inventories for the 22 October and 28 October tests obtained by Telstar should be accurate. This ratio is about 3. The ratio of the 22 to 28 October test as computed from Alouette is also 3, although this agreement is probably fortuitous.

For the 28 October detonation, the inventory of $\sim 1.2 \times 10^{25}$ electrons appears to be the most accurate. This figure was obtained independently by two groups (References 38 and 39), using different instruments. Although West's three inventory determinations scatter by a factor of 2, the value associated with a threshold of 1.0 MeV was selected since the background is lowest at that energy. This inventory value obtained from Starad is in rather good agreement with the Telstar result of 1.6×10^{25}, a fact that supports the Telstar figure for the 22 October explosion. Since the absolute values of the Starad fluxes are probably better than those of Telstar, the Starad value for the 28 October test is accepted and the Telstar ratio of 22 to 28 October inventories is used to find the inventory for the 22 October explosion. The final results for total electron inventories, $E > 0$ are:

- Event 1—22 October, 3.6×10^{25} electrons
- Event 2—28 October, 1.2×10^{25} electrons
- Event 3—1 November, 1.2×10^{24} electrons .

The low values for inventories deduced from Alouette were disregarded because the low-altitude orbit did not sample the intense fluxes and because of uncertainties in the geometric factors. The assumption used in the inventory calculation (flux at constant-L is independent of B) is obviously wrong on the basis of the Telstar distributions.

A substantial disagreement still remains between the values from Explorer 14 and the final values selected, the difference being a factor of 8 for Event 1 and a factor of 3.5 for Event 2. In the case of Event 2, the concentration of flux off the equatorial plane (Figure 6-24) would result in a lower inventory being measured by Explorer 14. The discrepancy for Event 1 still is unresolved. However, since the Telstar orbit is much superior for sampling the artificial belt, the Explorer 14 data have been ignored in computing inventories.

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